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ORIGINAL RESEARCH PAPER

Intracardiac vs Transesophageal Echocardiography for Left Atrial Appendage Occlusion With Watchman FLX in the U.S.

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ABSTRACT

BACKGROUND Intraprocedural imaging is critical for device delivery in transcatheter left atrial appendage occlusion (LAAO). Although pivotal trials of LAAO devices were conducted using transesophageal echocardiography (TEE), intracardiac echocardiography (ICE) is an emerging imaging modality.

OBJECTIVES This study compared outcomes after ICE- and TEE-guided Watchman FLX implantation in the SURPASS (SURveillance Post Approval AnalySiS Plan) nationwide LAAO registry.

METHODS Baseline characteristics were compared using chi-square and *t*-tests. Outcomes were reported in unadjusted and adjusted comparisons via propensity weighting.

RESULTS Between August 2020 and September 2021, LAAO was attempted in 39,759 patients at 698 sites, including 2,272 cases (5.7%) with ICE and 31,835 (80.0%) with TEE. ICE and TEE patients had similar baseline characteristics and mean procedural times (ICE 82 minutes vs TEE 78 minutes). ICE patients were less likely to receive general anesthesia (54% vs 98%, $P < 0.01$). Successful device implantation (98.3% vs 97.6%) and complete seal rates at 45 days were similar (n = 25,280; 83% vs 82%). Most adverse event rates were similar; unadjusted mortality rates at 45 days were 1.1% for ICE vs 0.8% for TEE ($P = 0.14$), and 1.0% vs 0.7% ($P = 0.27$) in adjusted analyses. Even after adjustment, pericardial effusion rates requiring intervention were significantly higher with ICE at 45 days (1.0% vs 0.5%; $P = 0.02$). This rate decreased as operators performed more ICE-guided procedures, although 82% of operators had performed <10 ICE-guided procedures overall.

CONCLUSIONS In the largest comparison to date, ICE use was infrequent. ICE and TEE both achieved high rates of complete LAAO. ICE was associated with significantly higher rates of pericardial effusion requiring intervention.
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ABBREVIATIONS AND ACRONYMS

3D = 3-dimensional

4D = 4-dimensional

AF = Atrial fibrillation

CT = computed tomography

DOAC = Direct oral anticoagulant

GA = General anesthesia

ICE = Intracardiac echocardiography

IRB = Institutional review board

LAAO = Left atrial appendage occlusion

NCDR = National Cardiovascular Data Registry

PDL = Peridevice leak

SURPASS = SURveillance Post Approval AnalySiS Plan

TEE = Transesophageal echocardiography

Left atrial appendage occlusion (LAAO) is used for stroke prevention in patients with atrial fibrillation (AF) who have reasons to seek an alternative to oral anticoagulation.[1] Intraprocedural imaging is crucial in LAAO to ensure safety during critical steps (eg, transseptal puncture, device deployment), and maximize efficacy through LAA orifice characterization, sizing, device selection and delivery.[2,3] The pivotal trials of the 2 currently approved LAAO devices were guided by intraprocedural transesophageal echocardiography (TEE).[4-7] Intracardiac echocardiography (ICE), however, is emerging as an alternative imaging technique for LAAO.[8]

Each of the 2 imaging modalities has unique strengths and limitations. TEE is widely available and familiar to most cardiologists, with established protocols that are routinely implemented to obtain high-resolution 3-dimensional (3D) imaging of intracardiac structures. However, TEE exposes patients to the risks of general anesthesia (GA) and esophageal injury.[9] ICE is established in the interventional electrophysiology community owing to advantages like near field imaging, avoidance of GA, lower turnover times, and decreased hospital expenses.[10,11] ICE requires additional vascular access, may require double transeptal puncture and significant intracardiac catheter manipulation, increasing the risk of pericardial injury.[10] Some of these limitations may be overcome as 3D and 4-dimensional (4D) ICE technologies become more widely available.[12]

Although ICE has been used in LAAO procedures since 2007, most of the available evidence is limited to single-center case series,[11,13-15] multicenter registries with few ICE-guided cases[16,17] or claims-based analyses limited to in-hospital events.[18] Meta-analyses of these studies suggest similar levels of effectiveness and safety between ICE and TEE, although the low event rates and study heterogeneity limit the generalizability of the findings.[8,19] In 2015, the American College of Cardiology National Cardiovascular Data Registry (NCDR) LAAO Registry was launched for post-market surveillance of the Watchman LAAO device (Boston Scientific), offering a unique opportunity to study intraprocedural imaging across several hospitals performing LAAO procedures with detailed periprocedural information and adjudicated endpoints.[3] This analysis used the LAAO Registry to describe temporal trends in ICE and TEE use since the U.S. approval of the Watchman FLX device, compare safety and effectiveness of LAAO with ICE vs TEE guidance, and explore how LAAO procedural volume with ICE impacts periprocedural outcomes.

METHODS

DATA SOURCE. The NCDR LAAO Registry is a nationwide observational, prospective, nonrandomized, multicenter registry where participating hospitals are required to report data for all LAAO procedures performed for Medicare beneficiaries in the United States since December 2015.[3] This reporting is required to qualify for reimbursement by the Centers for Medicare & Medicaid Services, but is estimated that >90% of participating hospitals voluntarily report all LAAO procedures, regardless of payer.[3] The LAAO Registry data and data collection methods have been detailed elsewhere.[3] Briefly, data are collected at discharge, 45 days (±14 days), 6 months (−30 days/+60 days), 1 year, and 2 years (±60 days) after the procedure. To ensure the completeness, validity, and accuracy of the data, the NCDR uses a rigorous Data Quality Reporting process that involves annual audits of approximately 5% of randomly selected sites.[20] The SURPASS (SURveillance Post Approval AnalySiS Plan) is nested within the NCDR LAAO and specifically includes all patients who had a Watchman FLX implant attempt. The LAAO Registry has been approved by Chesapeake Research Review, Inc, an independent institutional review board (IRB), and in accordance with 45 CFR 46.116(d) of the federal regulations, Chesapeake's IRB has waived the requirement for obtaining informed patient consent for this registry. The IRB has also waived Health Insurance Portability and Accountability Act authorization in accordance with 45 CFR 164.512(i)(2).

STUDY POPULATION. Patients who underwent a successful or aborted LAAO procedure with a

The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

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Watchman FLX device between August 2020 and September 2021 were included in this analysis. Aborted procedures, defined as those in which venous access was obtained, but in which a device was not ultimately deployed (ie, not released from the delivery catheter), were included to increase the generalizability of our findings and provide a more clinically relevant and methodologically rigorous analysis. We quantify the number of procedures in which additional interventions were performed in addition to LAAO (eg, pulmonary vein isolation), but this subgroup was excluded from subsequent comparative analyses. For the purpose of this study, eligible patients were assessed at discharge and at their 45-day follow-up.

STUDY ENDPOINTS. In the NCDR LAAO Registry, endpoints are adjudicated using a computer-based algorithm that has been validated against a formal clinical events committee, and that combines discrete combinations of registry data elements with standard event definitions. Manual adjudication is used when registry data elements are incomplete or conflicting.[21]

The main objective of this study was to compare the safety and effectiveness of TEE and ICE as periprocedural imaging modalities for LAAO. The type of intraprocedural imaging modality was at operator discretion. The key effectiveness endpoint was complete seal of the LAA, defined as the absence (ie, 0 mm) of residual peridevice leak (PDL) at the 45-day follow-up. PDL were further defined as small (ie, ≤5 mm) or large (>5 mm), in accordance with prior literature.[22] Implant success, defined as device release and deployment, was also assessed. Endpoints that required imaging assessment at the time of the procedure were evaluated using ICE or TEE, depending on the imaging modality used perioperatively. TEE was used for 45-day assessment.

The key safety endpoint was the occurrence of major adverse events at 45 days, defined as the composite of all-cause death, cardiac arrest, ischemic stroke, hemorrhagic stroke, undetermined stroke, transient ischemic attack, intracranial hemorrhage, systemic arterial embolism, major bleeding, major vascular complication, myocardial infarction, pericardial effusion requiring intervention, and device embolization. Additional safety endpoints of interest included the individual components of the primary endpoint as well as device-related thrombus (DRT), all of which were reported at hospital discharge and 45-day follow-up, when available.

STATISTICAL ANALYSIS. Temporal trends and use histograms for ICE alone, TEE alone, or combined ICE/TEE during the observation period were reported. For all subsequent analyses, patients were stratified according to ICE alone or TEE alone (which are subsequently referred to as "ICE" and "TEE"). The combined ICE/TEE subgroup was excluded from the analysis to perform a focused analysis of each modality used in isolation, especially because there is significant heterogeneity in the rationale for combined use (eg, to gain familiarity with ICE use, operator preference for ICE during transeptal puncture, difficulty performing the procedure with one modality alone, or bail out TEE use when ICE imaging fails).

Demographic, clinical, and procedural characteristics for the ICE and TEE groups were reported as counts (percentages) for categorial variables, and continuous variables were reported as mean and SD or IQR. These characteristics were then compared using chi-square and *t*-test analyses for categorical and continuous variables, respectively.

Outcomes were analyzed both at hospital discharge and at the 45-day follow-up among all patients who underwent a successful or aborted LAAO procedure with a Watchman FLX device (ie, the population in which the LAAO device implantation was attempted, whether it was successful or not). First, unadjusted outcomes were compared between ICE and TEE groups. Next, we used inverse probability of treatment weights to address potential selection bias in periprocedural imaging. We thus generated propensity scores (to predict use of either imaging modality) using a logistic regression model that included a list of preprocedural patient characteristics as well as operator- and hospital-level LAAO case volume. Logistic regression analyses of each outcome were then performed using the resulting assigned weights. To assess for any interaction between the hospital sites and the observed outcomes, an additional logistic regression analysis was performed with hospital site as fixed effect, as well as logistic regression test of interaction between hospital site, ICE, and TEE use.

Last, we described the distribution of ICE case volume among the operators during the study observation period, and evaluated the volume-outcome relationship at the operator level, by stratifying selected event rates by the ICE case volume of each operator. Analyses were conducted using SAS version 9.4 (SAS Institute).

RESULTS

TEMPORAL TRENDS IN ICE AND TEE USE. Between August 2020 and September 2021, the final analysis cohort included 39,759 attempted or aborted cases performed by 2,025 operators at 698 hospitals in the

United States (Central Illustration). Among these cases, 2,272 (5.7%) were performed with ICE guidance alone, 31,835 (80.0%) with TEE alone, and 5,652 (12.7%) with combined ICE/TEE (Supplemental Figure 1). From this baseline cohort, 2,052 ICE patients (90.3%) and 28,999 TEE patients (91.1%) completed 45-day clinical follow-up, and 1,643 ICE patients (72.3%) and 23,637 TEE patients (74.2%) completed the 45-day imaging follow-up. The majority of the hospitals (66.5%) and operators (71.8%) used TEE alone for their LAAO procedures, with <10% of hospitals or operators using either ICE alone or combined ICE/TEE guidance for their procedures (Figure 1). The proportion of cases per month using ICE alone was consistently low (approximately 4%-7%) during the 13-month observation period; similarly, monthly ICE+TEE use remained relatively consistent between 12% and 15% (Figure 2).

PREPROCEDURAL AND PROCEDURAL CHARACTERISTICS. Patients treated with ICE and TEE guidance had similar baseline characteristics in terms of age (mean, 76 years) and sex (40% female), with similar mean CHA_2DS_2-VASc (4.8) and HAS-BLED (2.4) scores, as well as mean ejection fraction of approximately 54% (Table 1). Compared with TEE patients, ICE patients were less likely to have paroxysmal AF (ICE 55.7% vs TEE 62.5%) and more likely to have persistent AF (26.5% vs 19.2%), with similar rates of permanent AF (approximately 18%). TEE patients were more likely to have prior cardiac structural interventions (ICE 6.7% vs TEE 8.4%), but similar rates of percutaneous coronary interventions or bypass grafting. In terms of antithrombotic medications that were prescribed and continued periprocedurally, the single largest group of patients in both arms was on a direct oral anticoagulant (DOAC) plus aspirin, which was used more commonly in TEE patients (ICE 45.0% vs TEE 48.9%). TEE patients were also more likely to be on DOAC plus a P2Y12 inhibitor (ICE 3.9% vs TEE 5.1%) or on warfarin plus aspirin (5.6% vs 8.5%), whereas ICE patients were more likely to be on DOAC alone (22.9% vs 21.1%) or dual antiplatelet therapy (13.1% vs 8.0%).

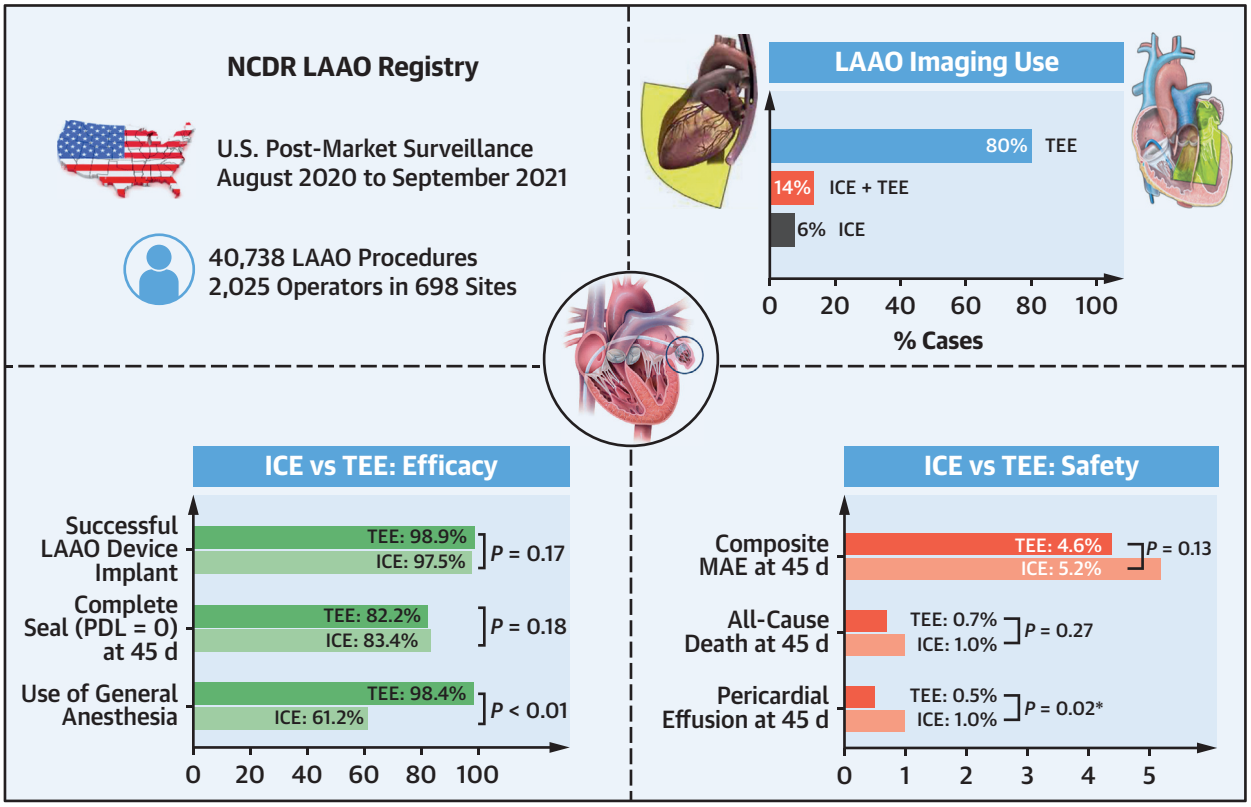
Compared with TEE patients, ICE patients were more likely to undergo preprocedural planning with computed tomography (CT) scans (ICE 38.1% vs TEE 19.8%), had longer mean procedural times (81.9 minutes vs 77.8 minutes) (Table 2), but were less likely to undergo GA (61.1% vs 98.7%) and more likely to be discharged on the same day of their LAAO procedure (29.0% vs 19.8%). The number of devices used was only 1 in 85%-90% of all patients in both groups, with a similar distribution of device sizes in the setting of similar LAA orifice maximum width (21 mm). Compared with TEE patients, ICE patients were more likely to undergo concomitant procedures (ICE 12.0% vs TEE 1.0%; primarily AF ablation).

EFFECTIVENESS ENDPOINTS. The rates of successful LAAO device implantation were similar in the ICE and TEE groups (ICE 98.3% vs TEE 97.6%) (Table 3). The rates of complete seal (ie, PDL = 0 mm) were similar in the ICE and TEE groups in-hospital (95.6% vs 95.5%); both rates declined by a similar amount by the 45-day follow-up evaluation performed under TEE guidance in both groups (ICE 83.2% vs TEE 82.2%), but without a statistically significant difference. There was a proportional increase in small PDL in each group from in-hospital (ICE 4.4% vs TEE 4.5%) to 45 days (16.3% vs 17.3%). Adjusted analyses showed similar results (Table 3). Although clinical follow-up was similarly high in both arms (ICE 90.1% vs TEE 90.0%) (Supplemental Tables 1 and 2), the proportion of patients who completed imaging follow-up at 45 days was lower in both arms, namely, 80.3% of ICE patients (64.4% via TEE, and 15.9% via CT scan) and 87.2% of TEE patients (80.0% via repeat TEE and 7.2% via CT scan) completed 45-day imaging. The baseline characteristics of patients who did not complete imaging follow-up were overall similar between ICE and TEE arms (Supplemental Table 3). The few unbalanced characteristics maintained similar proportions to the main study cohort at baseline (Table 2). For example, ICE patients who did not complete imaging follow-up had a lower prevalence of heart failure, compared with their counterpart in the TEE arm (ICE 35.81% vs TEE 40.37%), but in a similar proportion to the main study cohort (ICE 34.8% vs TEE 39.1%).

SAFETY ENDPOINTS. In unadjusted analyses, the occurrence of the in-hospital composite safety endpoint was similar between patients imaged with ICE or TEE (Table 4). Unadjusted all-cause mortality, however, was significantly higher among ICE patients (ICE 0.3% vs TEE 0.09%; $P = 0.01$). At the 45-day follow-up, however, unadjusted all-cause mortality was no longer significantly different between TEE and ICE patients (1.1% vs 0.2%; $P = 0.14$). Furthermore, after adjusting for preprocedural patient characteristics and LAAO case volume, there was no significant difference in mortality between ICE and TEE patients in-hospital or at 45 days (Table 4).

In both unadjusted and adjusted analyses, ICE patients were also found to have a significantly higher rate of pericardial effusion requiring intervention both in-hospital (adjusted, ICE 0.9% vs TEE 0.4%; $P = 0.01$) and at the 45-day follow-up (adjusted, 1.0% vs 0.5%; $P = 0.02$). The rates of all other secondary

CENTRAL ILLUSTRATION **Overview of ICE vs TEE Use in U.S. Clinical Practice**



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ICE = intracardiac echocardiography; LAAO = left atrial appendage occlusion; NCDR = National Cardiovascular Data Registry; TEE = transesophageal echocardiography.

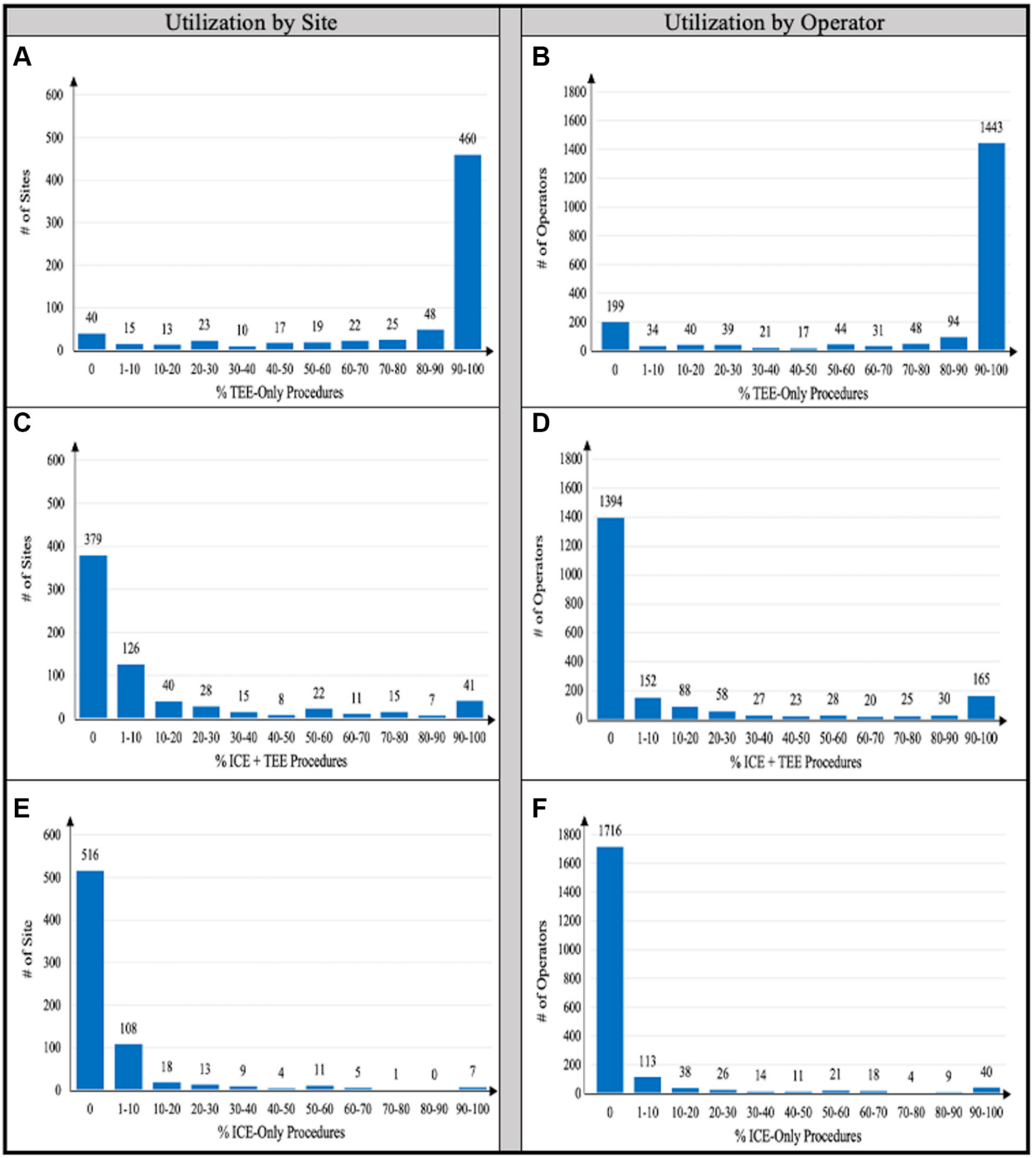
safety endpoints were similar between the 2 imaging modalities in both unadjusted and adjusted analyses.

In sensitivity analyses, an additional logistic regression with a fixed effect for hospital site showed no significant impact of hospital site on the safety endpoints that were statistically significant in unadjusted or adjusted analyses, namely, all-cause mortality ($P = 0.74$) or pericardial effusion requiring intervention ($P = 0.49$). A logistic regression test of interaction between hospital site, ICE and TEE use showed no significant impact of hospital site on all-cause mortality ($P = 0.84$) or pericardial effusion requiring intervention ($P = 0.49$).

Given the missing data for patients who did not complete imaging follow-up at 45 days, the difference in mean propensity scores was calculated based on ICE patients with and without imaging follow-up (0.023; 95% CI: 0.018-0.028) (Supplemental Table 3) and based on TEE patients with and without imaging follow-up is (0.027; 95% CI: 0.026-0.028). The 95% CI of the 2 groups were found to have a good amount of overlap.

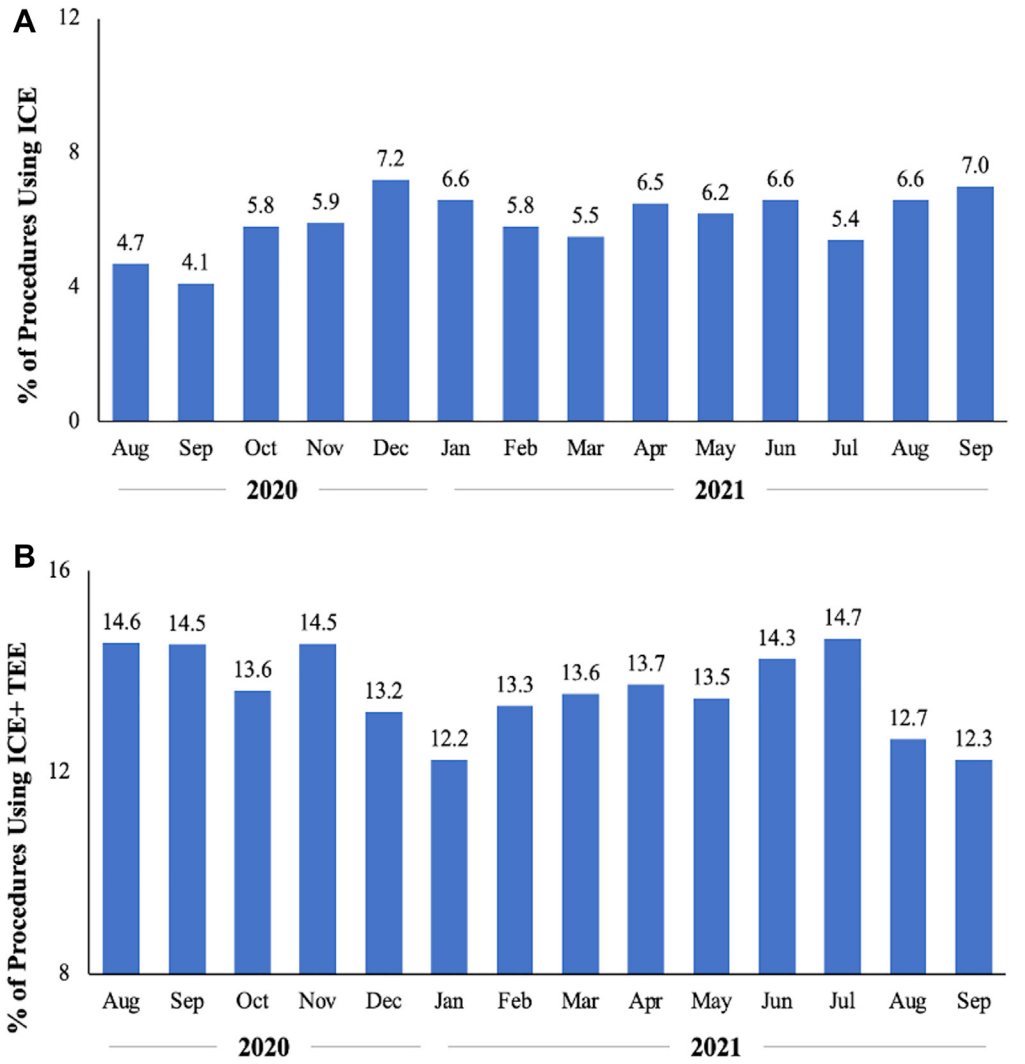
VOLUME-OUTCOME RELATIONSHIP IN ICE-GUIDED CASES. A total of 2,272 procedures were performed by 294 unique operators under ICE guidance alone. Of these 294 operators, the vast majority (241 [82.0%]) performed between 1 and 10 procedures in total during the study period, with a mean procedural time of 97.2 minutes and using a mean contrast volume of 47.1 mL. Among operators who performed 1-10 ICE-guided procedures, the rate of pericardial effusion requiring intervention was 1.4% (**Figure 3**). Operators with higher cumulative procedural volume, however, displayed progressively shorter procedural times and lower pericardial effusion rates. For example, among operators with ≥50 procedures, the procedural time was much shorter (67.3 minutes) and the pericardial effusion rate was also much smaller (0.8%), whereas the mean contrast volume remained stable at approximately 41.4 mL (**Figure 3**).

FIGURE 1 **Use Histograms for ICE and TEE, by Operator and by Site**



ICE = intracardiac echocardiography; TEE = transesophageal echocardiography.

FIGURE 2 **Monthly Trends in ICE and TEE Use**



Abbreviations as in Figure 1.

DISCUSSION

This analysis compared the safety and effectiveness of ICE and TEE guidance for LAAO across U.S. clinical practices. This analysis using data from the SURPASS Registry offers the unique opportunity to evaluate a large cohort with adjudicated endpoints and follow-up beyond hospital discharge, which can improve our understanding of the key outcomes associated with these 2 imaging modalities. This nationwide analysis provides several notable and clinically relevant findings. First, the use of ICE alone remained consistently low across the study period, limited to approximately 4%-7% of LAAO procedures. Second, ICE and TEE were associated with similar procedural effectiveness, both in terms of successful implantation and the key endpoint of complete LAA seal with no residual PDL at the 45-day follow-up (>80% in both arms). Although the procedure time was longer under ICE guidance, there was significantly less use of GA in ICE-guided cases, and patients in the ICE arm had higher rates of same-day discharge. Third, even after adjustment, ICE use remained associated with a 2-fold increase in the risk of pericardial effusion requiring intervention (approximately 1% ICE vs 0.5% TEE at 45 days).

TABLE 1 Baseline Preprocedural Characteristics

	ICE (n = 2,272)	TEE (n = 31,835)	*P* Value
Demographic characteristics			
Age, y	75.8 ± 8.0	76.4 ± 7.9	0.0005
Female sex	907 (39.9)	13,018 (40.9)	0.36
BMI, kg/m^2	29.6 ± 7.0	29.7 ± 6.7	0.36
Race/ethnicity[a]			
White	2,048 (92.3)	29,747 (95.5)	<0.0001
Black/African American	153 (5.7)	1,262 (4.1)	<0.0001
Hispanic or Latino	98 (4.5)	890 (2.9)	<0.0001
Clinical characteristics			
CHA_2DS_2-VASc score	4.8 ± 1.5	4.8 ± 1.5	0.24
Congestive heart failure	791 (34.8)	12,449 (39.1)	<0.0001
Hypertension	2,083 (91.7)	29,194 (91.7)	0.94
Diabetes mellitus	837 (36.9)	11,350 (35.7)	0.26
Stroke	524 (23.1)	6,851 (21.5)	0.09
HAS-BLED score	2.5 ± 1.0	2.4 ± 1.0	<0.0001
Abnormal renal function	402 (17.7)	4,584 (14.4)	<0.0001
Labile INR	129 (5.7)	1,722 (5.4)	0.60
Increased fall risk	920 (40.6)	13,146 (41.4)	0.44
Clinically relevant bleeding event	1,404 (61.9)	19,125 (60.2)	0.11
Atrial fibrillation pattern			<0.0001
Paroxysmal (self-terminated within 7 days)	1,257 (55.7)	19,735 (62.5)	
Persistent (>7 days)	599 (26.5)	6,076 (19.2)	
Long-standing persistent or permanent	402 (17.9)	5,781 (18.3)	
Prior cardiac structural intervention (any)	151 (6.7)	2,677 (8.4)	0.0034
PCI	449 (19.8)	6,745 (21.2)	0.10
CABG	278 (12.2)	4,096 (12.9)	0.38
Ejection fraction, %	54.3 ± 10.2	54.0 ± 9.9	0.44
Antithrombotic medications at Discharge			
Warfarin monotherapy	52 (2.3)	784 (2.5)	0.62
Warfarin + aspirin	126 (5.6)	2,689 (8.5%)	<0.0001
Warfarin + P2Y12 inhibitor	10 (0.44)	223 (0.70)	0.15
DOAC monotherapy	517 (22.9)	6,692 (21.1)	0.04
DOAC + aspirin	1,018 (45.0)	15,545 (48.9)	0.0003
DOAC + P2Y12 inhibitor	88 (3.9)	1,609 (5.1)	0.01
DAPT	296 (13.1)	2,529 (8.0)	<0.0001
SAPT	72 (3.2)	871 (2.7)	0.22
Triple therapy	49 (2.2)	504 (1.6)	0.04
No OAC or antiplatelet	29 (1.3)	192 (0.60)	0.0001
Other	6 (0.27)	144 (0.45)	0.19

Values are mean ± SD or n (%). [a]Patients were allowed to self-report >1 race or ethnicity.

BMI = body mass index; CABG = coronary artery bypass graft; DAPT = dial antiplatelet therapy; DOAC = direct oral anticoagulant; ICE = intracardiac echocardiography; INR = international normalized ratio; OAC = oral anticoagulant; PCI = percutaneous coronary intervention; SAPT = single antiplatelet therapy; TEE = transesophageal echocardiography.

LONGITUDINAL TRENDS IN ICE USE. The use of ICE to guide LAAO has been studied since 2007 and is a frequent topic at scientific symposia and continuing medical education events. Therefore, it seems surprising that the real-world adoption of ICE as a standalone imaging modality for LAAO was limited to only approximately 6% of all LAAO cases in 2020-2021. This limited adoption seems to align with prior claims-based reports of ICE use in only 2%-3% of all LAAO cases between 2016 and 2018.[18] The 6% ICE use rate in this nationwide cohort is just one-half of the 12% ICE use rate from a recent cohort of patients undergoing implantation of the Amulet LAAO device (Abbott Laboratories).[17] However, in the Amulet study, eligible operators had previously performed ≥5 ICE-guided LAAO cases, representing a selected subgroup of only 16 operators from 13 sites in the United States, in contrast with the 2,025 operators across 698 sites in our study.

Despite the low adoption rate of ICE as a standalone imaging modality, it seems likely that ICE use will continue to increase over time in LAAO. Combined ICE/TEE use rates were already much higher during our study period (12%-15%): operators may initially use both modalities as they accrue more experience before transitioning to ICE alone, a pattern that may be further accelerated as higher quality, multidimensional ICE catheters become available. Similar trends of ICE adoption rates have been observed in the case of transcatheter closure of atrial septal defects, where ICE use increased from 9.7% of all cases in 2003 to 50.6% in 2014.[23]

ICE VS TEE: EFFECTIVENESS CONSIDERATIONS. The low ICE adoption rate may be partially related to commonly reported concerns that ICE imaging may not provide as thorough of an assessment of LAAO, especially device seal. Notably, our study found that both TEE and ICE were associated with similar effectiveness, with high rates of complete seal at hospital discharge (approximately 95%) and at 45 days (approximately 82%). Small residual leaks (ie, ≤5 mm) have been associated with higher odds of stroke and systemic embolism, compared with no leaks.[22] The 82% complete seal at 45 days is improved over the prior NCDR analysis of Watchman outcomes (73.4%) and likely represents the improvements associated with the Watchman FLX device.[7] This finding helps to address the concern that ICE may provide inferior imaging to guide device placement and could lead to suboptimal closure.[10,11] In contrast, our data suggest that ICE imaging provides sufficient and reliable information to evaluate for PDL after LAAO device deployment.

ICE use was also associated with some net benefits relative to TEE, including a 30% decrease in the need for GA and higher rates of same-day discharge. Although ICE obviates the need for independent TEE operators, this factor did not lead to shorter

procedure times, even after excluding patients with concomitant procedures like AF ablation. ICE cases were on average 10 minutes longer in our cohort, a statistically significant difference. Although meta-analyses suggest that procedural times may be similar between ICE and TEE,[8,19] ICE may require more catheter manipulation and time to cross the interatrial septum and obtain the target views. Direct comparisons are limited by variation in the definition of procedural time. In our study, procedure time was defined from the time patients entered the laboratory until the time operators broke scrub. This definition does not include the in-room anesthesia recovery time, which may ultimately result in equivalent procedural times. Limited operator experience with LA ICE may also have contributed to longer procedural times, with our volume-outcome analyses showing a decrease of >20 minutes in mean procedural time after the first 30 ICE cases. As newer TEE models such as micro-TEE and mini-TEE (with 3D capabilities) are introduced into the market, which allow TEE to be more regularly conducted with deep sedation instead of GA in many centers,[24] the cost-effectiveness considerations of ICE and TEE will continue to evolve over time and require further study.

TABLE 2 Procedural Characteristics

Variable	ICE (n = 2,272)	TEE (n = 31,835)	*P* Value
Preprocedural planning CT scan	864 (38.1)	6,298 (19.8)	<0.001
Procedure time, min	81.9 ± 34.8	77.8 ± 65.6	<0.001
Contrast volume, mL	43.5 ± 33.6	41.9 ± 36.2	0.03
Sedation			<0.0001
Minimal sedation (anxiolysis)	12 (0.53)	29 (0.09)	
Moderate sedation (conscious sedation)	869 (38.3)	393 (1.2)	
Deep sedation or GA	1,387 (61.1)	31,327 (98.7)	
LAA orifice max width, mm	21.8 ± 5.1	20.9 ± 4.2	<0.001
No. of devices used			<0.001
1	2,046 (90.1)	27,374 (86.0)	
≥2	226 (9.9)	4,461 (14.0)	
Device size, mm			<0.0001
20	254 (11.4)	4,173 (13.4)	
24	642 (28.7)	10,083 (32.5)	
27	749 (33.5)	9,687 (31.2)	
31	422 (18.9)	5,065 (16.3)	
35	167 (7.5)	2,054 (6.6)	
Same-day discharge	659 (29.0)	7,653 (24.0)	<0.001

Values are mean ± SD or n (%).

CT = computed tomography; GA = general anesthesia; LAA = left atrial appendage; PCI = percutaneous coronary intervention; TAVR = transcatheter aortic valve replacement; other abbreviations as in Table 1.

ICE VS TEE: SAFETY CONSIDERATIONS. It is important to highlight that the adjusted rate of pericardial effusion requiring intervention was twice as high in the ICE group compared with TEE. This finding raises concerns especially in light of recent reports from the LAAO Registry with first-generation Watchman devices, where pericardial effusion requiring intervention was associated with a substantially higher risk of major adverse events (including death) both in-hospital and after discharge compared with other periprocedural events like DRT or PDL.[25] At the same time, it is reassuring that the absolute unadjusted rates of pericardial effusion were overall low in both arms of our study (ICE 1.1% vs TEE 0.5% at 45 days). This finding aligns with the continued decrease in pericardial effusion events reported over the course of the collective experience with LAAO devices,[25] such as the recent Watchman FLX pivotal trial (approximately 0.75%). Although most of these rates in the literature are derived from TEE-guided procedures, this downward trend is also observed when comparing our ICE cohort in 2020-2021 with prior real-world experiences of ICE-guided Watchman FLX implantation in 2019 (2.2%).[15]

TABLE 3 Effectiveness Endpoints, In-Hospital and at 45 Days

	In-Hospital Outcomes						Outcomes at 45-Day Follow-Up					
	Unadjusted Outcomes			Adjusted Outcomes			Unadjusted Outcomes			Adjusted Outcomes		
Measure	ICE (n = 2,272)	TEE (n = 31,835)	*P* Value	ICE	TEE	*P* Value	ICE (n = 1,643)	TEE (n = 23,637)	*P* Value	ICE	TEE	*P* Value
Successful implant per patient	98.3	97.6	0.02	98.4	97.8	0.17		N/A			N/A	
Complete seal												
Residual leak = 0 mm	95.6	95.5	0.67	96.1	95.5	0.18	83.2	82.2	0.60	85.5	82.2	0.19
Residual leak ≤5 mm	4.4	4.5		4.0	4.5		16.3	17.3		15.7	17.3	
Residual leak >5 mm	0.0	0.03		0.0	0.0		0.5	0.4		0.5	0.4	

Values are %.

Abbreviations and in Table 1.

TABLE 4 Safety Endpoints, In-Hospital and at 45 Days

	In-Hospital Outcomes						Outcomes at 45-Day Follow-Up					
	Unadjusted Outcomes			Adjusted Outcomes			Unadjusted Outcomes			Adjusted Outcomes		
Measure	ICE (n = 2,272)	TEE (n = 31,835)	*P* Value	ICE	TEE	*P* Value	ICE (n = 2,052)	TEE (n = 28,999)	*P* Value	ICE	TEE	*P* Value
Major adverse event[a]	1.7	1.3	0.08	1.9	1.3	0.07	5.4	4.8	0.28	5.2	4.4	0.14
All-cause death	0.31	0.09	0.01	0.30	0.09	0.10	1.1	0.8	0.14	1.0	0.7	0.27
All stroke	0.2	0.08	0.15	0.2	0.08	0.27	0.3	0.3	0.81	0.3	0.3	0.71
Ischemic	0.2	0.07	0.10	0.2	0.07	0.22	0.3	0.3	0.70	0.3	0.2	0.54
Hemorrhagic	0.0	0.0	0.99	-	-	-	0.05	0.05	0.99	-	-	-
Undetermined	0.00	0.01	0.99	-	-	-	0.0	0.01	0.99	-	-	-
Major bleeding	1.4	1.1	0.15	1.5	1.1	0.11	3.9	3.5	0.40	3.8	3.2	0.19
Major vascular complications	0.2	0.2	0.41	0.2	0.2	0.63	0.4	0.2	0.16	0.4	0.2	0.29
Myocardial infarction	0.04	0.02	0.38	0.06	0.02	0.50	0.2	0.2	0.38	0.2	0.1	0.49
Pericardial effusion requiring intervention	0.8	0.4	0.0005	0.9	0.4	0.01	1.1	0.5	0.001	1.0	0.5	0.02
Requiring cardiac surgery	0.3	0.09	0.02	0.3	0.09	0.07	0.3	0.1	0.046	0.3	0.1	0.10
Requiring pericardiocentesis	0.7	0.3	0.004	0.7	0.3	0.051	0.9	0.4	0.005	0.8	0.4	0.055
Device-related thrombus	0.0	0.06	0.63	-	-	-	0.2	0.2	0.49	0.2	0.2	0.84
Device embolization	0.0	0.03	0.99	-	-	-	0.05	0.04	0.56	0.04	0.03	0.88

Values are %. [a]Any major adverse event included death, cardiac arrest, ischemic stroke, hemorrhagic stroke, undetermined stroke, transient ischemic attack, intracranial hemorrhage, systemic arterial embolism, major bleeding, major vascular complication, myocardial infarction, pericardial effusion requiring intervention, and device embolization. Abbreviations as in Table 1.

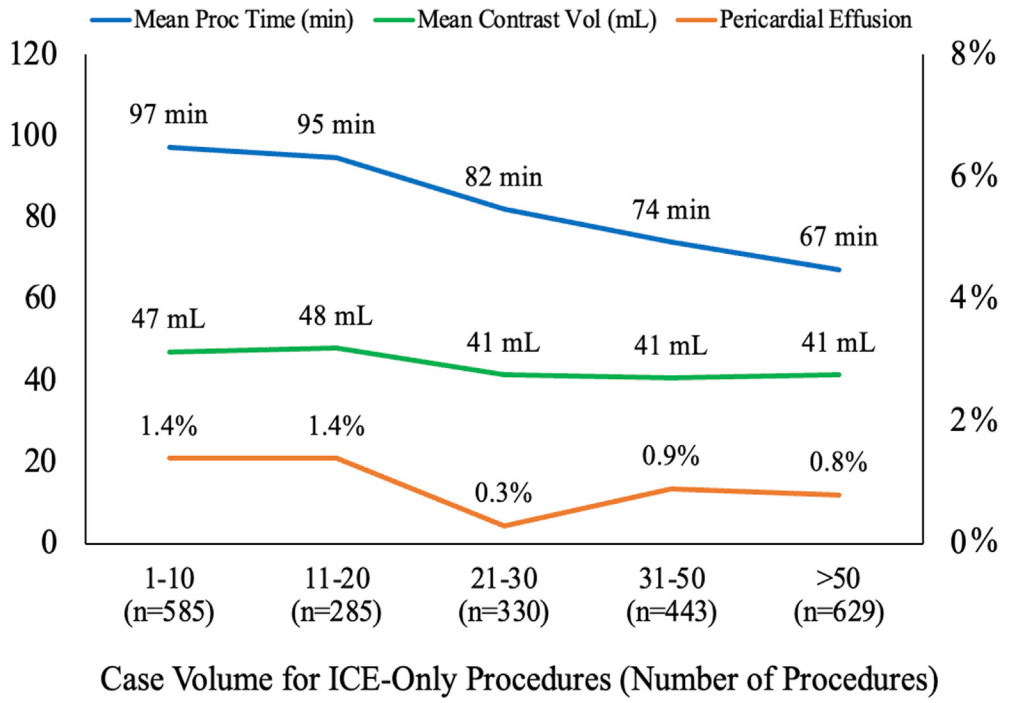
Furthermore, our analysis captures relatively early ICE experience; 82% of the ICE cases were done by operators who had performed <10 ICE-guided implants. These outcomes were compared with outcomes in cases performed by operators who were, on average, much more experienced with TEE guidance. Such differential experience likely contributed to the observed differences in pericardial effusion events. It is notable that the rate of pericardial effusion among ICE operators decreased dynamically within our study period as operators performed more ICE-guided procedures, which suggests the presence of a learning curve. As operator experience with ICE-guided LAAO increases, further analyses will be less susceptible to confounding as a result of differential operator experience.

Physicians who are considering adopting ICE to guide LAAO implantation should be aware of the higher rate of pericardial effusion requiring intervention that was observed in this analysis. We recommend concomitant use of ICE and TEE as operators gain experience with ICE, as well as training and/or proctoring by physicians experienced with ICE-guided LAAO, which may also help to minimize the risk of complications during initial experiences with ICE-guided cases. Based on expert recommendations, preprocedural planning with CT or 3D TEE should be conducted for ICE-guided LAAO; notably, patients undergoing ICE-guided LAAO in our cohort were more likely to undergo preprocedural CT.

NEXT STEPS IN EVALUATING THE VALUE OF ICE IN LAAO. In the coming years, it will be important to prioritize the improvement of certain aspects of the ICE technology to further increase the safety and effectiveness in LAAO. Heterogeneity in intracardiac ICE location during each procedure may influence adverse event rates, although these data are not available in our analysis. ICE manipulation near the right ventricular free wall and outflow tract, or the thin-walled coronary sinus can increase the risk of cardiac perforation, as well as the extensive ICE catheter manipulation during double transeptal access or within the LA chamber.[26] To date, 4 different LAA views from the left heart have been described, ideally to be used in a complementary fashion to maximize implant success; although expert consensus documents are starting to emerge, standardized ICE imaging protocols are needed to disseminate best practices that can improve both periprocedural effectiveness and safety.[26] The use of integrated ultrasound imaging with preprocedural CT scans may also help to facilitate navigation and improve safety. Last, the introduction of 4D ICE may markedly decrease the need for catheter manipulation in the LA, and the availability of newer, softer catheters may further promote safety among operators as they become familiar with the ICE technology.

STUDY LIMITATIONS. As in any observational registry, events may be undercounted owing to incomplete follow-up and resulting ascertainment bias

FIGURE 3 Volume-Outcome Relationship in ICE-Guided Cases



Abbreviations as in Figure 1.

through the 45-day clinical visits, loss to follow-up may lead to selection bias, and there may be residual or unmeasured confounding that influences our study results. However, the similarly high rate of clinical follow-up in the 2 arms decreases the concern that mortality or nonfatal periprocedural complications could have asymmetrically compromised follow-up rates, together with the observation that the baseline characteristics of patients who did not complete imaging follow-up were overall similar between the ICE and TEE arms. Furthermore, the good amount of overlap in the 95% CIs of the difference in propensity scores based on ICE and TEE patients who did and did not complete imaging follow-up suggests that missing data seem to be missing at random and likely had limited impact on our analyses.

Although our clinical registry can adjudicate clinical events with a high degree of certainty, we did not have information on the type and duration of antithrombotic therapy beyond hospital discharge, which could influence both effectiveness outcomes like DRT or safety outcomes like postprocedural bleeding. Canceled procedures (ie, procedures that were stopped before obtaining venous access) and procedures with devices other than the Watchman FLX were not available in the limited dataset obtained from the NCDR LAAO Registry; thus, the results may not be generalizable to other commercially available LAAO devices.

ICE operators primarily relied on the 2D ICE technology, and results may vary as higher resolution 3D and 4D ICE technologies enter the market. The combined ICE/TEE subgroup was excluded from the analysis owing to significant heterogeneity in the rationale for combined use, however this group may partly represent cross-over from ICE to "bail out" TEE, and as such could influence the success rates reported for each arm.

CONCLUSIONS

Despite widespread use in other atrial procedures, ICE use remains limited in LAAO procedures. ICE and TEE are associated with similar procedural effectiveness, including successful implantation and complete LAA seal with no residual PDL at the 45-day follow-up. However, ICE use remained associated with a higher relative risk of pericardial effusion requiring

intervention compared with TEE, even after adjustment. In light of these findings, further studies of the 2 approaches are warranted to rigorously evaluate outcomes with the 2 techniques.

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PERSPECTIVES

COMPETENCY IN PATIENT CARE AND PROCEDURAL SKILLS: Intraprocedural imaging is crucial during percutaneous LAAO to guide device placement in a safe and effective manner. TEE remains the preferred imaging modality in clinical practice, although ICE is used in a minority of procedures. In the largest comparison to date, ICE and TEE achieved similar effectiveness and safety profiles, but ICE did have a higher risk of pericardial effusion requiring intervention.

TRANSLATIONAL OUTLOOK: Further studies are needed to define the optimal workflow and technique for ICE-guided imaging, including the minimal number of views and standardization in the intracardiac ICE catheter position during LAAO procedures. Learning curve analyses should also explore describe periprocedural complication rates as operators gain expertise with this novel technology.

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APPENDIX **For supplemental tables and a figure, please see the online version of this paper.**